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SENSITIVITY STUDY WITH A LIMITED AREA MODEL: EXTRATROPICAL STORM DELTA OVER THE CANARY ISLANDS

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Introduction

The numerical solutions of Limited-Area Models (LAM) are sensitive to changes in their configurations. One of the most common ways of utilizing those models is by performing sensitivity experiments (Stein and Alpert, 1993). In this study, continuation of recent works of Jorba et al., 2007 and Marrero et al., 2007, we show preliminary results associated with 27 configurations of the Weather Research & Forecasting Model (WRF-ARW) (Michalakes et al., 2005) initialized with the 0.25º reanalysis of the European Center for Medium Range Weather Forecasting (ECMWF) for the extratropical storm Delta. Delta affected the Canary Islands (Fig.1) with a warm core associated in 850 hPa (Fig. 2) on 28 November 2005, causing significant damage related to high sustained wind and intense gusts over some of the islands (Table 1). Modifications in domain dimension and location, horizontal resolution, number of vertical levels and physics permit us to survey their impact in the 10 m wind solution. The factor separation method was used to quantify in detail the effect of the variation of these parameters on the simulated 10 m wind speed. Highly non linear interaction of flow with topography due to the existence of the warm core at the mountain top level was the main factor that produced gusts over 160 km/h at La Palma, 90 km/h at the coast in Tenerife, and over 215 km/h in its mountain top (Jorba et al.,2007; Marrero et al., 2007).

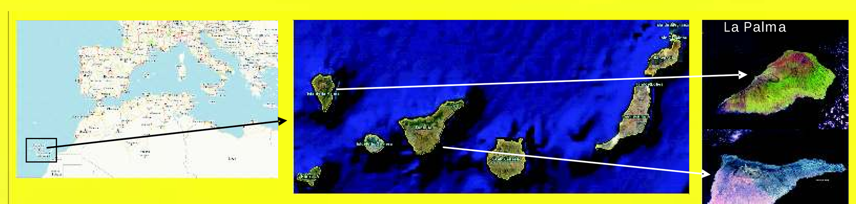

Fig. 1. Location of the Canary Islands. Tenerife and La Palma are the islands of the archipelago with the steepest orography and were the most affected by Delta storm.

Table 1. Maximum wind speeds and gusts at 10 m registered by the major observatories and airports of the archipelago under the influence of Delta.

Station name	10 m wind speed (km/h)	10 m wind gust (km/h)	Time UTC 28 Nov 2005
Hierro airport	67	118	18:00
Tazacorte	31	59	12:30
La Palma airport	104	166	19:00
La Gomera	48	92	16:00
Tenerife north airport	30	70	16:00
S/C de Tenerife	57	132	21:00
Tenerife south airport	87	134	21:40
Izaña	180	218	20:00

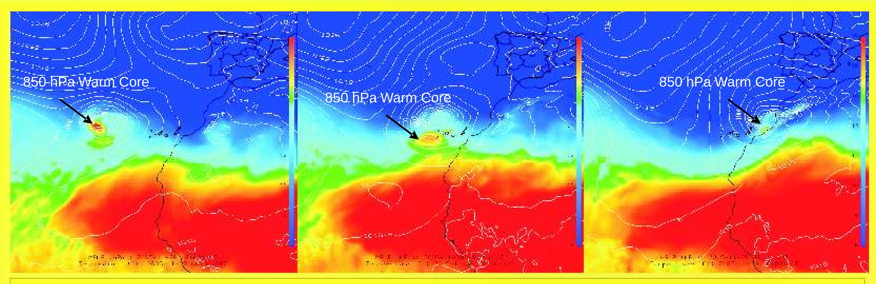

Fig. 2. ECMWF reanalysis of extratropical storm Delta showing the warm core in 850 hPa when going through the Canary Islands.

Numerical Modeling Setup

To explore their impact in the numerical solution we have designed several non hydrostatic experiments taking into account geometrical factors, like the size and position of the mother domain, number of nested grids, horizontal resolution and number of vertical levels (Fig. 5); and physical parameterizations (Fig. 6). To specify the size of the mother domain we have used HYSPLIT backward trajectories (Fig. 7 and 8) to evaluate the propagation of the advective lateral boundary condition error at several levels. The 31 level scheme has been interpolated to obtain the 41 and 61 level distributions. The size of the mother domain has been positioned 10º S, 10º E y 10ºW in relation to the base case configuration, and a reduction of 25% and 50% has also been applied to the centred case. Twelve combinations of physical schemes has been obtained using 3 microphysics, 2 surface layers, 2 boundary layers and 2 cumulus options. Non-nested domains have been defined to resolutions of 2 km, 3 km, 6 km, 9 km and 27 km. An additional hydrostatic case forms a cluster of 27 experiments to explore the variability of the numerical solution.

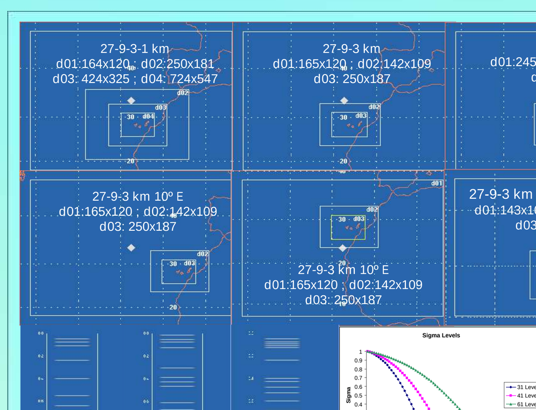

Fig. 5. Domain configurations and vertical distributions.

microphysics options
1.b) Lin et al.
1.c) WSM 3-class simple ice
1.e) Ferrier (new Eta) microphysics
surface-layer option
3.1.a) Monin-Obukhov
3.1.b) Monin-Obukhov (Janjic Eta)
boundary-layer option
4.a) YSU scheme
4.b) Mellor-Yamada-Janjic (Eta) TKE
cumulus option
5.a) Kain-Fritsch (new Eta)
5.b) Betts-Miller-Janjic

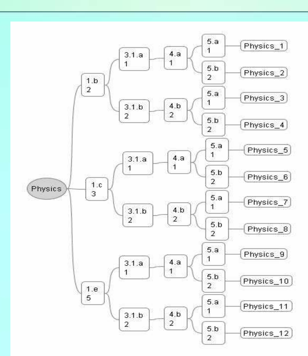

Fig. 6. Combinations of WRF-ARW physics schemes used.

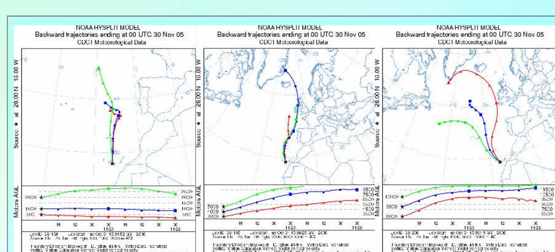

Fig. 7. HYSPLIT backward trajectories at several levels used to evaluate the size of the mother domain to diminish the effect of LBC advective errors in 48 forecast hours.

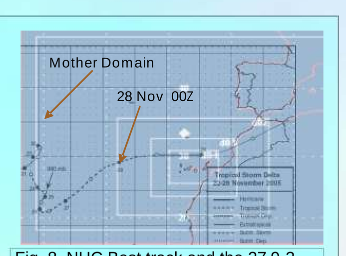

Fig. 8. NHC Best track and the 27-9-3-1km multiple nested grid case. Initialization on November 28th 00Z guarantees a well posed lateral boundary condition configuration.

Factor Separation Methodology

To quantify the impact on the 10 m wind solution due to modifications of the WRF-ARW model setup parameters, we have used the factor separation technique formulated by Stein and Alpert (1993), following the methodology adopted by Jankov et al. (2005). Based on this methodology:

$$f_{xy}-f_0=\left(f_x-f_0\right)+\left(f_y-f_0\right)+\hat{f}_{xy}$$

where f_0 represents the chosen solution variable of the Control Run Experiment (CRE). Our CRE corresponded to the phys5 (Fig. 6) option, 27-9-3 km two-ways nesting centred grid and 31 levels scheme configuration. The CRE choice was based in computational economy (most of the experiments are run with this domain and physics configuration). The solution variable used f was the maximum grid point 10 m horizontal wind speed in the 48 hours run (Fig. 9). Now, f_x represents the maximum 10 m wind speed produced by a run that has one of the configuration parameters of the model changed, f_y the maximum wind speed when another parameter is changed, and f_{xy} when the two simultaneous parameters are changed. $\hat{f}_{xy}$ stands for a term reflecting the nonlinear interaction between the two different configuration parameters. The notation presented in Table 2 will be used to indicate the different model configurations used with this technique.

Table 2. Configuration Parameter options available in the 27 experiments to evaluate their impact using the factor separation methodology.

Configuration Parameters	Notation
Microphysics Options	**MP**
Lin et al.	LIN
WSM 3-class simple ice	WSM
Ferrier (new Eta) microphysics	FER
Surface-Layer Options & Boundary-Layer Options	**SL&BL**
Monin-Obukhov & YSU Scheme	MO-YSU
Monin-Obukhov (Janjic Eta) & Mellor-Yamada-Janjic (Eta) TKE	MOJ-MYJ
Cumulus Options	**CU**
Kain-Fritsch (new Eta)	KF
Betts-Miller-Janjic	BMJ
Most Inner Grid Resolution	**GR** 27, 9, 6, 3, 2 or 1 km
Nesting Two-Ways Activation	**NA** Yes or No
Number of WRF-ETA scheme Vertical Levels	**NL** 31, 41 or 61
Percentage of Mother Grid Reduction	**PGR** 25% or 50%
Position of Mother Grid	**PMG** 0º Centered, 10º E, 10ºW or 10ºS
Hydrostaticity	**HY** Yes or No

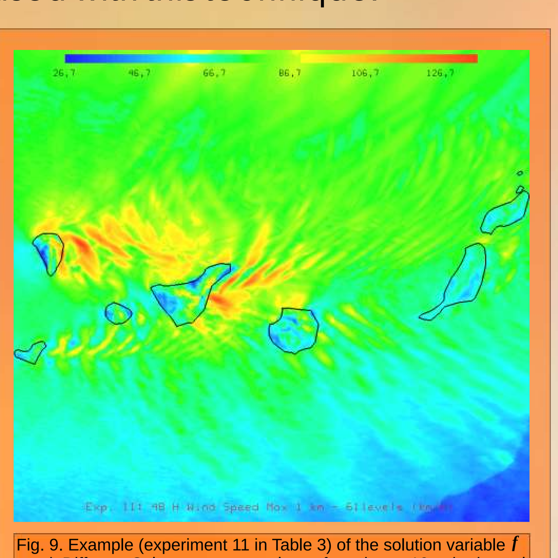

Fig. 9. Example (experiment 11 in Table 3) of the solution variable f used. Different Colors represent values of maximum 10 m horizontal wind speed in the 48 hours run.

Results

A total of 24 configurations have been compared against the CRE, with cursive and bold letters in Table 3 identifying the options that were varied. Nonlinear interactions were calculated in cases 5,6,7,8 y 9. In experiments 11, 20, 22, 23 and 24 only the factor f_{xy} was determined. Percentage changes for every grid point were plotted in order to measure the magnitude of variation in a common domain of 3 km resolution. This percentage change was calculated as

$$\left(\frac{f_x-f_0}{f_0}\right)\times100,\quad \left(\frac{f_{xy}-f_0}{f_0}\right)\times100 \quad or \quad \left(\frac{\hat{f}_{xy}-f_0}{f_0}\right)\times100$$

Histogram diagrams for every experiment showing the number of grid points per percentage class into a limited area around La Palma and Tenerife (Fig. 8) were added to summarize this information. Maximum and minimum values and statistics moments of order 0,1 and 2 (Table 4) are also shown. Only the most relevant graphics and histograms are presented in Figure 11.

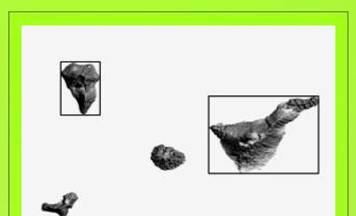

Fig. 10. Histogram and Statistics are calculated in the square areas.

Table 3. Experiments setting used to compare against the CRE. Cursive and bold letters indicate the parameters (notation defined in Table 2.) that have been varied in every experiment.

Experiment	MP	SL&BL	CU	GR	NA	NL	PGR	PMG	HY
CRE	WSM	MO-YSU	KF	3	Y	31	0	C	N
EXP. 1	WSM	MO-YSU	***BMJ***	3	Y	31	0	C	N
EXP. 2	WSM	***MOJ-MYJ***	KF	3	Y	31	0	C	N
EXP. 3	***L***	MO-YSU	KF	3	Y	31	0	C	N
EXP. 4	***F***	MO-YSU	KF	3	Y	31	0	C	N
EXP. 5	WSM	***MOJ-MYJ***	***BMJ***	3	Y	31	0	C	N
EXP. 6	***L***	***MOJ-MYJ***	KF	3	Y	31	0	C	N
EXP. 7	***F***	***MOJ-MYJ***	KF	3	Y	31	0	C	N
EXP. 8	***L***	MO-YSU	***BMJ***	3	Y	31	0	C	N
EXP. 9	***F***	MO-YSU	***BMJ***	3	Y	31	0	C	N
EXP. 10	WSM	MO-YSU	KF	***2***	Y	31	0	C	N
EXP. 11	WSM	MO-YSU	KF	***1***	Y	***61***	0	C	N
EXP. 12	WSM	MO-YSU	KF	3	Y	***41***	0	C	N
EXP. 13	WSM	MO-YSU	KF	3	Y	***61***	0	C	N
EXP. 14	WSM	MO-YSU	KF	3	Y	31	***25***	C	N
EXP. 15	WSM	MO-YSU	KF	3	Y	31	***50***	C	N
EXP. 16	WSM	MO-YSU	KF	3	Y	31	0	***E***	N
EXP. 17	WSM	MO-YSU	KF	3	Y	31	0	***W***	N
EXP. 18	WSM	MO-YSU	KF	3	Y	31	0	***S***	N
EXP. 19	WSM	MO-YSU	KF	3	Y	31	0	C	***Y***
EXP. 20	WSM	MO-YSU	KF	***2***	***N***	31	0	C	N
EXP. 21	WSM	MO-YSU	KF	3	***N***	31	0	C	N
EXP. 22	WSM	MO-YSU	KF	***6***	***N***	31	0	C	N
EXP. 23	WSM	MO-YSU	KF	***9***	***N***	31	0	C	N
EXP. 24	WSM	MO-YSU	KF	***27***	***N***	31	0	C	N

Table 4. Statistics associated to La Palma and Tenerife area values. 25% of the highest values are marked in red, and 25% of the lowest in blue. This is useful to distinguish the relative most relevant changes.

Experiment	Max.	Min.	Mean	Std. Deviation	Skewness
EXP. 1	24	-17	0.3	4.7	0.9
EXP. 2	105	-21	17.4	25.8	1.0
EXP. 3	43	-18	2.9	4.9	1.5
EXP. 4	32	-44	-4.4	8.9	0.0
EXP. 5	27	-39	-3.9	8.3	-0.4
EXP. 6	45	-72	-3.8	10.2	-1.2
EXP. 7	44	-38	1.6	10.0	-0.2
EXP. 8	28	-39	-0.4	5.4	0.2
EXP. 9	22	-30	-0.7	7.2	-0.3
EXP. 10	39	-16	3.3	6.6	0.9
EXP. 11	93	-44	3.7	14.3	1.0
EXP. 12	41	-13	1.9	5.9	1.8
EXP. 13	41	-14	2.3	6.0	1.2
EXP. 14	84	-34	1.2	10.4	4.9
EXP. 15	39	-28	0.4	7.3	1.1
EXP. 16	60	-38	2.2	10.0	0.9
EXP. 17	43	-18	1.0	5.0	2.0
EXP. 18	42	-23	1.1	7.7	0.4
EXP. 19	31	-48	0.3	11.8	-0.3
EXP. 20	83	-19	11.5	14.0	1.2
EXP. 21	85	-19	10.3	13.5	1.1
EXP. 22	51	-37	-2.4	14.0	0.6
EXP. 23	75	-42	-6.8	17.4	0.9
EXP. 24	112	-48	-15.1	22.8	1.9

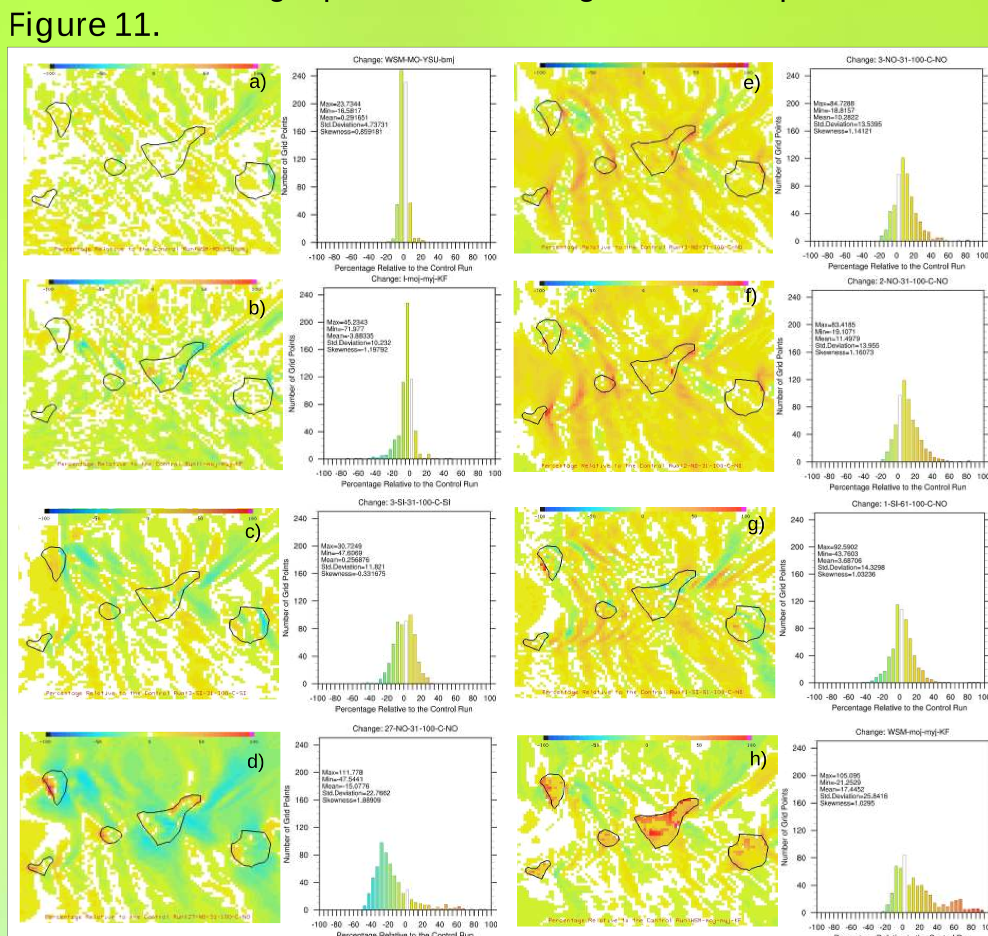

Figure 11. Percentages relatives to the CRE with histograms associated to La Palma and Tenerife areas and their statistics are show in figures a) to h), corresponding to experiments 1, 6, 19, 24, 20, 11 and 2. A shift to negative values are shown in figures a) to d). In contrast, positive increments in maximum velocities are presented in figures e) to h).

Discussion

The study of the results shows that most of the modifications of the model parameters had a moderated to strong impact in the 10 m maximum wind speed solution. The most important positive variations were associated to modifications of the BL&SL parameterization, increase in horizontal resolution and size domain diminishing without nesting. The most negative percentages of change were due to the nonlinear interaction between MP and BL&SL in the case of *L* and *MOJ-MYJ*, decreasing of horizontal resolution and to the hydrostaticity activation. Neither Increasing in number of levels to 41 or 61 nor changes in cumulus parameterization showed a significant variation. Size mother domain reduction with two-ways nesting grids activated had a minor impact in the position of the storm modifying slightly the pattern of stagnation areas and the position of the maximum winds. The hydrostatic case showed a systematic diminishing of the maximum wind speed in leeside locations. Symmetric histograms in experiments 4, 7 and 8 demonstrated an spatial shift in the positions of the wave pattern associated to the maximum winds. Percentage change graphics depict wavelike features associated to the capability of the model to reproduce the amplitude and spatial phase of the mountain wave structures. Strong hydraulic jumps at leeside of Tenerife and La Palma are emphasized by some of the configurations (experiments 11, 20 and 21) or minimized by others (experiments 22, 23 , 24 and 19). These variations are related to resolution, nesting capability and hydrostaticity. To conclude, and taking into account that more cases need to be run to reach more conclusive results, it appears that If an ensemble for 10 m wind speed were to be designed, model runs with different BL&SL schemes, horizontal resolutions, hysdrostaticity options and number of nested grids should be included as an efficient way to increase the spread. Future work will focus on other strong wind cases with and without warm core interacting with Canary Islands topography.

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